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The absence of suitable external criteria is a recurrent problem for test, battery, and inventory developers in selecting items or tests for inclusion in final operational instruments. This report presents a computing algorithm developed for use when no adequate external selection criterion is available. The algorithm uses a multiple linear regression technique and an accretion variable selection process to start with a large pool of variables and select a minimum subset which can account for the domain of reliable variance measured by all variables in the pool. Two sample applications are presented: (1) selection of a subset of tests from a battery of 56 tests; and (2) selection of a subset of job attitude items from a pool of 348 items. (Author)

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VARSEL: VARIABLE SELECTION FOR MULTIPLE-PURPOSE PREDICTION SYSTEMS IN THE ABSENCE OF EXTERNAL CRITERIA

By

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The absence of suitable external criteria is a recurrent problem for test, battery, and inventory developers in selecting items or tests for inclusion in final operational instruments. This report presents a computing algorithm developed for use when no adequate external selection criterion is available. The algorithm uses a multiple linear regression technique and an accretion variable selection process to start with a large pool of variables and select a minimum subset which can account for the domain of reliable variance measured by all variables in the pool. Two example applications are presented; (a) selection of a subset of tests from a battery of 56 tests and (b) selection of a subset of job attitude items from a pool of 348 items.

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PREFACE

This research was completed under Project 7734, Development of Methods for Describing, Evaluating, and Structuring Air Force Operations; Work Unit 77340501, Impact of Work Related Factors on Job Satisfaction and Career Decisions.

One of the first objectives of the work unit was to develop an Occupational Attitude Inventory (OAI) covering the job satisfaction domain of airmen. Because of the multiple-purpose nature of the OAI, there was no adequate external criterion to use for final selection of items to be included in the operational OAI. Further, no suitable item selection techniques were available for use under the "no adequate external criteria" circumstances. This report describes development of the computing algorithm which was used to select the final set of OAI items.

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VARSEL: VARIABLE SELECTION FOR MULTIPLE-PURPOSE PREDICTION SYSTEMS IN THE ABSENCE OF EXTERNAL CRITERIA

I. INTRODUCTION

Test and inventory developers frequently obtain large item pools from which to select a final set of items. Laborious efforts to define the area of interest and to develop corresponding items culminate in the final critical developmental stage—selection of the set of items to be included in the operational instrument. The ideal item selection approach is to administer the entire pool of items to a sample population, correlate the items with an external criterion such as success in school, and select those items having the highest correlations with the criterion. However, suitable external selection criteria do not always exist either because the measures are not available for the sample population, or the developing instrument is to be used for multiple-purpose predictions and by definition there are no specific definable item selection criteria. The selection problem is similar for developing test batteries except that the variables of interest are complete tests instead of specific items.

In the absence of suitable external criteria, the standard approach for selecting a final set of variables is to use some type of total score (or factor scores) as the selection criteria. The procedures present several disadvantages. First, selecting variables which correlate with total or factor scores tends to produce a set of highly related or redundant variables with a corresponding loss of variables accounting for relatively unique components of score variance. Secondly, many variables and test scores fail to meet the requirements for valid factor analyses as explained by Guilford (1952). Linear dependencies among scores, skewed variable distributions, and factor extraction inadequacies are only a few of the data and procedural discrepancies which can introduce criterion error when factor scores are used in variable selection exercises. Finally, use of total and factor score criteria unnecessarily limits the future applications of many measurement instruments, particularly diagnostic instruments, because of the specificity of the selection criteria.

Some investigators have recognized the tendency for correlational techniques to select redundant variables and propose accretion item selection procedures which take into account item intercorrelations during the selection process (Bryson, 1972; Moonan & Pooch, 1966). Their accretion procedures partially solve the redundancy problem but have limited effect on the loss of variables primarily measuring specific variance and subsequent restrictions on the future utility of the measurement instrument. The problem remains—how to start with a large pool of variables and select the smallest subset which can capture the domain of non-error variance measured by the full set?

This report presents a variable selection algorithm which test developers may find useful in constructing measurement instruments. The algorithm is titled VARSEL, variable selection for multiple-purpose prediction systems in the absence of external criteria. A description of the VARSEL algorithm, including theoretical considerations and computational options, will be followed by two example applications: (a) selection of a subset of tests from a battery of 56 tests, and (b) selection of a subset of job attitude items from a pool of 348 items.

II. VARSEL

In this section the computing procedures, input data and parameter requirements and restrictions, and hardware requirements of the VARSEL algorithm will be described.

Developmental Considerations

Two systems, a deletion and an accretion system, were considered for the variable selection process. Both systems involved application of multiple linear regression techniques. The deletion system sequentially removed variables which were most highly predictable from remaining items in the pool. However, it became apparent that the approach could discard a variable which had small amounts of variance uniquely held in common with several variables and subsequently delete some of those common variance items. The resulting loss of unique variance could defeat the purpose of the selection system. The accretion system does not present this problem and thus was used for the VARSEL algorithm.

The accretion or accumulative system (summarized in Figure 1) is designed to start with a single item or set of items and iteratively select additional items which contribute the greatest amount of unique variance to the prediction system. At each iteration the selected set of items (S) is used to predict (R^2) the remaining N-S individual items. The resulting N-S R^2 values are then individually subtracted from 1.0. The $1\text{-}R^2$ values represent the amount of item variance unpredicted by the set of S items and thus the amount of unique variance the item will contribute to the prediction system. The item with the highest $1\text{-}R^2$ value is selected for inclusion in the S set of items, and the process continued until any one of several cutoff parameters is reached.

As thus far expressed, there is a major weakness in the selection system. Unique or specific item variance is composed of true and error variance. Items with large error variances are likely to be selected even if their true variance is "perfectly" predicted by previously selected items. Therefore, the selection system was designed to take into account item reliabilities, when they are available, by subtracting the R^2 values from the respective reliabilities rather than using the $1.0\text{-}R^2$ item selection criteria. This can be done because a test's reliability r_{11} is a measure of reproducible test score variance. Items thus identified are selected according to their contribution of unique "reliable" variance to the prediction system. Use of reliability values in the selection process is particularly useful when tests or subtests are being identified for inclusion in a test battery.

Several VARSEL iteration cutoff options may be specified by users as shown in Figure 2. Variable selection iterations may be stopped when (a) a predetermined number of variables has been selected, (b) when prediction system contribution of unique reliable variance of the next item to be selected falls below some specified minimum, or (c) when all items have been selected. Options are also available for selecting the initial or starting variables as follows: (a) VARSEL will select the most unique of N items on the first selection iteration, or (b) the user may specify the first item selected, or (c) the user may specify a group of items to be initially selected. The third option permits the developer to select variables he definitely wants in his operational inventory. For example, those interested in ensuring that a previously defined factor structure of a pool of variables is maintained can select for each factor a few variables having high factor loadings as the initial system (S) predictors.

Operating Requirements

VARSEL requires as input an upper triangular correlation matrix, in column or row sequence. Figure 3 summarizes some of the VARSEL input and computing requirements. The maximum number of variables that can be handled is 400. Inputing reliabilities is optional. Other options include methods for selecting initial variables and establishing iteration cutoff criteria. When options are not specified, the following default values are used: Reliabilities = 1; selection of most unique item as the starting S variable; and iteration cutoff = 10 items selected. For those interested in computer requirements, selecting from a 400 variable correlation matrix requires about an 80K core memory. Cholesky's routine (Overall & Klett, 1972; System 1360, 1966) is used to develop the R^2 values and the efficiency of the method is illustrated by the computation of 54,285 R^2 values in 7.75 central processor unit (CPU) minutes (.0086 seconds per R^2 value) on a UNIVAC 1108. VARSEL took 8.2 minutes to completely process a 330 variable matrix including CPU time and input and output when the starting variable was given by the user. Processing required 14.7 minutes when VARSEL selected the first item. The additional time was required to calculate the inverse of the 330 x 330 correlation matrix and re-read the original matrix when the most unique item was identified by VARSEL. Cholesky's routine provides unique solution R^2 values and is usually associated with factor analysis programs. The VARSEL source program was written by Westphal, Mathon, McQuiston, & Greenway (1976) in FORTRAN V and the control cards are free format. A brief flow chart of VARSEL is shown in Figure 4.

III. EXAMPLE APPLICATIONS

Two example applications are given. The first demonstrates the use of reliabilities and the selection of a subset of tests for inclusion in a test battery. The second example illustrates the selection of a minimum subset of specific items from a large pool of items. The item selection example also demonstrates how to ensure that the process maintains the factor structure of an original pool of items. Both examples show the VARSEL effectiveness in reducing a set of variables with minimal loss in system variance.

At each iteration, VARSEL . . .

- Uses a multiple linear regression routine to predict each unselected item where selected items (S) are used as predictors. Results in N–S R^2 values. N = total number of items in input correlation matrix.
- Subtracts resulting R^2 values from 1.0; $1.0-R^2$ = amount of unpredicted item variance. Reliability (r_{11}) used instead of 1.0 if r_{11} is known; $r_{11}-R^2$ = amount of unpredicted reliable variance.
- Selects item which has greatest amount of unpredicted variance; i.e., selects item which contributes greatest amount of unique variance (unique reliable variance if r_{11} is used) to the prediction system.

Figure 1. **Accretion item selection technique.**

Cutoff Options – Stop when . . .

- A predetermined number of items (S) are selected; or
- Prediction system unique variance contribution of the candidate selection item falls below a specified minimum; or
- All items have been selected.

Selection of Starting Variable(s)

- VARSEL selects most unique of N items based on unique reliable variance if r_{11} values are available; or
- User selects starting item or set of items

Iteration Print Suppression Options also Available

Figure 2. **VARSEL options.**

Required Data

- Upper triangular correlation matrix; $N \leq 400$
- Reliabilities (1's are default values)
- Selection cutoff and print options (default is 10 items and print all iterations)
- Initial selected item IDs (default is most unique of N items)

System Requirements

- 80K core memory if N = 400
- Tape drives, disk packs, or drum memory
- FORTRAN V compiler

Efficiency Example

- 54,285 R^2 values computed by Cholesky's routine in 7.75 minutes or .0086 second per R^2
- Complete VARSEL processing of 330 variable matrix in 8.2 minutes including input and output when starting variable is given

Figure 3. **Selected system requirements and computing efficiency.**

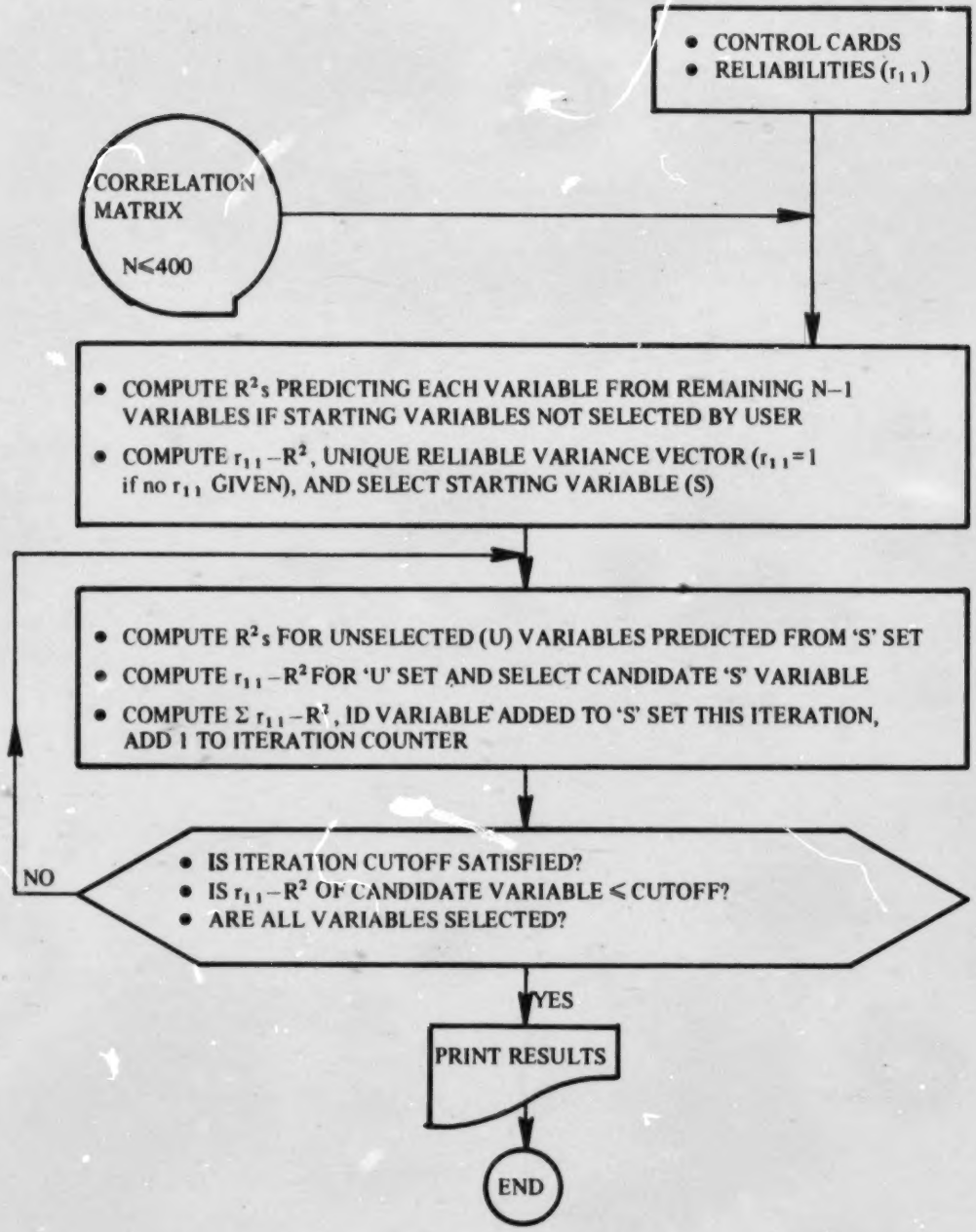
• CONTROL CARDS
• RELIABILITIES (r_{11})
CORRELATION MATRIX
N≤400
• COMPUTE R^2s PREDICTING EACH VARIABLE FROM REMAINING N–1 VARIABLES IF STARTING VARIABLES NOT SELECTED BY USER
• COMPUTE $r_{11}-R^2$, UNIQUE RELIABLE VARIANCE VECTOR (r_{11}=1 if no r_{11} GIVEN), AND SELECT STARTING VARIABLE (S)
• COMPUTE R^2s FOR UNSELECTED (U) VARIABLES PREDICTED FROM 'S' SET
• COMPUTE $r_{11}-R^2$ FOR 'U' SET AND SELECT CANDIDATE 'S' VARIABLE
• COMPUTE $\Sigma\ r_{11}-R^2$, ID VARIABLE ADDED TO 'S' SET THIS ITERATION, ADD 1 TO ITERATION COUNTER
• IS ITERATION CUTOFF SATISFIED?
• IS $r_{11}-R^2$ OF CANDIDATE VARIABLE ≤ CUTOFF?
• ARE ALL VARIABLES SELECTED?
NO
YES
PRINT RESULTS
END

Figure 4. **VARSEL abbreviated flow chart.**

Test Selection Example

The Army Air Force Aviation Psychology Program research reports (Guilford & Lacey, 1947, p. 903) contain an intercorrelation matrix of 65 experimental and operational classification (aptitude) tests developed and used during World War II with pilots and navigators. The tests had reliability coefficients available and are here used as a test of the VARSEL algorithm for reducing a test battery to a subset of tests measuring the same domain of reliable variance. Reliabilities ranged from .49 to .94 but the mean reliability was .80.

The test battery had undergone extensive and laborious research efforts to develop unique tests. The intercorrelation matrix had r's ranging from −.01 to .62 but most of the r's were in the teens and low twenties. These r's are remarkably low for a large number of aptitude tests. The test battery already contains seemingly unique tests and should pose a rigorous trial for the selection routine. Before VARSEL application, nine tests were removed from the matrix because of obvious inconsistencies in the correlation matrix.

Table 1 presents an extract of selected iterations and tests from the VARSEL summary output. The column values are the unique reliable variances ($r_{1.1} - R^2$) of the unselected tests which are unpredictable by the set of tests which have been selected by the given iteration. Asterisks in the iteration column indicate that the test has been selected in the current or a previous iteration. Iterations 1, 10, 20, 30 and 40 are shown for 13 of the 56 tests. On the first iteration there were eight user selected tests placed in the predictor set (S). Test 35 has the highest column value after iteration 1, $r_{11} - R^2 = .759$, so will contribute the most unique reliable variance to the predictor set and is selected to be placed in the S set of items in iteration 2.

Table 1. **VARSEL Iteration Summary Print Extract for 56 Tests**

Iteration Number		1	10	20	30	40
Sum of Unique Reliable Variance		25.3	17.34	10.33	5.30	1.83
Variable Selected This Iteration		—	9	17	3	18
Selection Candidate For Next Iteration		53	56	44	34	14
Number of Predictor System Variables		8	17	27	37	47
Variable ID	Description	$r_{11} - R^2$	$r_{11} - R^2$	$r_{11} - R^2$	$r_{11} - R^2$	$r_{11} - R^2$
1	Map Memory	.395	.340	.286	.244	.203
4	Estimation of Length	.419	.359	.335	.269	.239
6	Directional Orientation	.451	.398	.326	.249	.209
14	Objectivity of Perception	.507	.372	.343	.308	.250
16	Aerial Orientation	.408	.339	.249	.219	.193
24	Pattern Assembly	.432	.357	.329	.265	.239
34	Tool Function	.422	.400	.383	.354	****
35	AAF Word Knowledge	.439	.398	.285	.232	.199
39	Spatial Orientation I	.348	.313	.289	.216	.196
44	Speed of Identification	.537	.506	.471	****	****
45	Numerical Operations I	.153	.146	.138	.125	.101
53	Finger Dexterity	.759	****	****	****	****
56	Discrimination Reaction Time	.606	.569	****	****	****

The sum of the column values, unpredicted reliable variances, is shown immediately below the iteration number. Users may find the sum helpful in determining when to stop the iteration selection if no specified number of variables must be selected. The sum is an error sum of squares value and represents the amount of reliable domain variance that will be lost if the selection process stops at the respective iteration. In the current example, a stop criteria was used which directed the iteration process to stop when all unselected tests had a specified percentage of their reliable variance predictable by the selected tests.

Using a stop criterion of $r_{11}-R^2 = .25$ and a starting set (S) of eight user selected tests, the iteration process stopped at the 40th iteration. There were nine tests unselected and they had 75 percent or more of their unique reliable variance accounted for by the 47 selected tests.

In iteration 1, test number 14, Objectivity of Perception, has 51 percent of its reliable variance unaccounted for by the initial selected set of eight tests. Fifteen percent of test 14's total score variance, .66 (r_{11}) minus .51, is variance held in common with the eight selected tests. The unaccounted for reliable variance decreases to 25 percent by the 40th iteration when 47 tests have been selected. By definition the test with the largest column value is the candidate item for the next iteration, so test 14 is the candidate test for selection in iteration 41. Since test 14's contribution of unique reliable variance is equal to the $r_{11}-R^2$ cutoff, the iteration process stops and nine tests are unselected. The nine tests may be removed from the test battery as having most of their variance in common with the selected set of tests.

Removing 16 percent of the tests from a test battery which appeared to be composed of unique tests could represent a considerable savings in personnel, examinee and examinor's time. A comparison of the reliabilities of the unselected tests and the correlations of those tests' scores with scores predicted from the selected tests may clarify the efficiency of the VARSEL process. The values are in Table 2.

Table 2. **Unpredicted Reliable Variance, Reliabilities, and Predictability of Test Scores for Nine Unselected Tests**

Variable ID	Description	Unpredicted Reliable Variance	r_{11}	R
1	Map Memory	.203	.66[a]	.68[b]
4	Estimation of Length	.239	.60	.60
6	Directional Orientation	.209	.74	.73
14	Objectivity of Perception	.250	.66	.64
16	Aerial Orientation	.193	69	.71
24	Pattern Assembly	.239	.59	.59
35	AAF Word Knowledge	.199	.79	.77
39	Spatial Orientation I	.194	.63	.66
45	Numerical Operations I	.101	.64	.73

[a]Test reliabilities as determined by split-half, test-retest, or internal consistency (KR_{20}) methods.

[b]Multiple correlations predicting obtained scores for unselected tests using a combination of test scores from selected tests.

After taking into account test reliabilities, the final unselected tests had reliabilities much below average. In a trial VARSEL run which did not use the reliabilities, several of these less reliable tests were selected early in the iteration process demonstrating the importance of using reliabilities.

Using the selected tests to predict individuals' scores on the nine unselected tests, correlations (R) between actual and predicted scores ranged from .59 to .77. In each case, the correlation between predicted and actual scores approached or exceeded the tests' reliabilities demonstrating the efficiency of the selection process.[1]

[1]Tests may correlate with other variables more than they correlate with themselves; i.e., correlations of test scores with other variables may exceed the test reliabilities. Maximum possible correlation of a test with another variable is equal to the correlation of the test's true and obtained scores; the value is estimated by taking the square root of the reliability coefficient.

Item Selection Example

An experimental Occupational Attitude Inventory (OAI) was being developed to measure all facets of job satisfaction in the military work environment (Tuttle, Gould, & Hazel, 1975). Planned usage of the OAI was as an Air Force wide, a career-ladder specific, or a within career ladder job satisfaction diagnostic instrument as well as for predictive studies of reenlistment, performance, and attitude changes. These multiple objectives for OAI use precluded the use of any particular external criteria in the item selection process. During the developmental stage, a comprehensive pool of 348 items was developed to sample the domain of job attitudes of Air Force enlisted airmen. The problem was to select the smallest subset of items which would capture the domain of attitude variance measured by the full set of 348 attitude items.

The 348 item OAI was administered to a random sample of 3,100 airmen. Previous studies have indicated that most job dissatisfaction is among first-term airmen (Gould, 1972). Therefore, responses of 1,340 first-term airmen were used in the item reduction exercise. The 348 OAI items were first factor analyzed and 36 dimensions or facets of job satisfaction identified before VARSEL processing began. Approximately two items having high factor loadings, yet which subjectively measured different specific elements of the satisfaction dimension, were selected per factor for use as the starting set of selected items. This was done to ensure that the factor structure of the entire domain of 348 job attitude items was maintained during the selection process. Because of the extreme length and varied content of the experimental OAI, it was not practical to obtain item reliabilities so a simple estimate procedure was used. One item, "The chance to work at your own pace," was placed in the OAI twice as item numbers 235 and 306. The item is the same format as the other 346 items and is considered to be a relatively simple and straight forward statement of an aspect of a job. Therefore, the correlation between items 235 and 306, r = .77, was accepted as the best available estimate of the individual items' reliabilities (r_{11}). Instead of subtracting the R^2 values from 1.0 $r_{11}-R^2$ or $.77-R^2$ values were used to determine the potential unique reliable variance contribution of each selection candidate item. Because the same reliability is applied to all items, the r_{11} value plays little role in the actual selection process but does help to determine when to stop selecting items.

Table 3 presents an extract of the VARSEL iteration summary output obtained for the first five OAI item selection iterations. Seventy-one "user selected" variables were placed in the predictor set on the first iteration. Item 91 becomes the candidate variable for selection in iteration 2 because it has the largest unpredicted unique reliable variance, $r_{11}-R^2 = .575$, and will thus, contribute the largest amount of domain variance prediction by being placed in the predictor system. In the current example, there was no required number of items to select so VARSEL was allowed to continue until all items were selected. The iteration which would define the final set of OAI items was then selected by the user. The unique reliable variance sum was used as one indicator of when to stop selecting items. Iteration 128 was selected as the stopping point resulting in a final set of 200 items for the OAI. The sum of the unique reliable variance in the set of remaining 148 items was .36 so the average loss of unique reliable variance per item was .0024. The candidate item for selection in iteration 129 had an $r_{11}-R^2 = .075$ so less than 8 percent of its "true" variance was not accounted for by the set of S variables. Most of the unselected items had less than 1 percent of their "true" variance unaccounted for by the S set of items; a highly successful result. The 200 selected items were refactored and the original 36 dimensions were obtained. The factor structure of the domain of atitude items was maintained during the item selection process. However, the number of items per factor with moderate or high factor loadings decreased substantially and several items selected did not load moderately on any factor.

IV. CONCLUSION

In summary, a computing algorithm has been developed to select minimum subsets of items or tests which capture the domain of reliable variance measured by a large pool of items or tests. Innovators may discover several additional uses for the VARSEL algorithm.

Using an accretion method, the variable which will contribute the most unique variance if included in the final instrument, or which represents the greatest loss in domain variance if excluded, is selected at each

Table 3. **VARSEL Iteration Summary Print Extract for 348 OAI Items**

Iteration Number		1	2	3	4	5
Sum of Unique Reliable Variance		48.25	47.33	46.39	45.42	44.52
Variable Selected This Iteration		—	91	55	115	16
Selection Candidate For Next Iteration		91	55	115	16	56
Number of Predictor System Variables		71	72	73	74	75
Variable ID	Description	$r_{11}-R^2$	$r_{11}-R^2$	$r_{11}-R^2$	$r_{11}-R^2$	$r_{11}-R^2$
1	Chance to feel you are accomplishing something	.109	.109	.107	.107	.106
2	Air Force's efforts to remove irritants	.376	.376	.373	.372	.371
3	Geographical area to which you are assigned	****	****	****	****	****
6	Need for frequent retraining within your specialty	.455	.453	.448	.448	****
91	Cost of living in the area to which you are assigned	.575	****	****	****	****
115	Adequacy of lighting in the immediate work area	.455	.454	.454	****	****
148	Opportunity for personal growth	.022	.021	.021	.021	.021
235	Chance to work at your own pace	.211	.209	.208	.208	.208

iteration. Cutoff parameters stop the process when a specific number of items are selected or when the amount of unique variance contributed by a selected item falls below a specified value.

In demonstrations of the efficiency of the algorithm, a subset of 200 items was selected from a pool of 348 job satisfaction items. Of the items eliminated from the pool, an average of only two-tenths of one percent of "reliable" variance per item could not be accounted for by the selected items. In another application selecting tests from a battery of 56 seemingly unique tests, nine tests were eliminated from the battery. Using the selected tests to predict unselected test scores resulted in higher predicted vs actual score correlations than the individual tests correlated with themselves (reliabilities), thus demonstrating the efficiency of the selection process.

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